§3. Study of Interaction between Plasma and EM Wave in Prospect of Application of Millimeter & Sub-millimeter Waves

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In FIR FU, gyrotrons as electromagnetic wave sources with wavelength from millimeter to sub millimeter have been developed and their applications have been advanced. On the other hand, electron cyclotron heating (ECH) techniques with high power gyrotron systems are used for the transport control and diagnostics as one of the main subjects in PRC, University of Tsukuba. Spatial transport in plasmas is strongly connected to global structures of plasma parameters. This is essentially true for fusion, non-neutral and gyrotron plasmas magnetized and confined in conductor walls. We have taken a first step of linear analysis of global structure of drift waves with wide and integrated scope of various plasmas. We constructed a Vlasov–based equation in a cylindrical geometry with the guiding-center approximation including arbitrary radial distributions of density and anisotropic temperature for multi-species. Contribution of finite Larmor-radius is taken into account and nonlinear coupling between plasmas and waves is also taken into account in this work. This may also be useful for generalized analysis of gyrotron power generation placed in our scope.

In the experiment from 2011, a micro-wave reflectometer system has been installed to evaluate the behavior of the EM waves in the core region on GAMMA 10. In 2012, we modified the reflectometer system to 2-channel type system for measuring two different locations at the same time. In the radial direction, the phase difference between the density fluctuations at the different two radial positions are measured and global spatial structure of Alfvén ion cyclotron (AIC) waves are clearly obtained. Figure 1 shows the phase differences between the density fluctuations measured at two different positions when one frequency is fixed at 10 GHz and another frequency is scanned from 8 to 11 GHz. The frequency of 10 GHz is corresponded to be cutoff frequency at the location of r/a ~ 0.7, where r and a are the radial location and the plasma radius, respectively. As shown in the figure, the phase difference becomes π outside of the location of r/a ~ 0.7 and becomes zero inside. The AIC waves have several discrete peaks (peak1 to 3) in their frequency spectrum and have been considered to be excited as eigenmodes in the plasma. A global structure in the radial direction has been detected. The mechanism of the phase reversal in the density fluctuations is now under investigation.

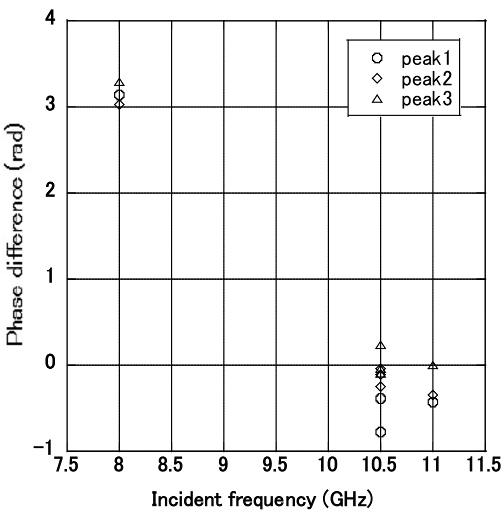

Fig. 1 Phase difference between the density fluctuations at two different locations when one frequency is fixed as 10 GHz and another frequency is scanned from 8 to 11 GHz.

As the wave-particle interactions, low-frequency fluctuations around 0.1 MHz, of which frequencies are differential frequencies between discrete peaks of the AIC waves, are clearly detected in the frequency spectrum of the east-end high energy ion detector (eeHED). High-energy ions are detected as burst-like signals and each burst is considered to contain several tens ions. The period of these bursts corresponds to the frequency of the low-frequency fluctuations. The transport of high-energy ions is also measured in the radial direction in the central cell. These fluctuations are observed only in the axial direction and not in the radial direction. Then, pitch angle scattering of high-energy ions in the velocity space owing to spontaneously excited Alfvén wave are indicated. If the transport of these high-energy ions along the magnetic field line is mainly caused by the collisional process, the signal of high-energy ions should be observed continuously at the end.

In FIR FU, development of advanced gyrotrons has been carried out. For this purpose, properties of the electron beam in a magnetron injection gun (MIG) have been intensively investigated. Based on this study, an effective method has been established to create a laminar electron beam in a non-uniform electric and magnetic fields and to minimize the space charge effect. Then, newly designed MIG's have been applied to advanced gyrotrons. One of them is a high power sub terahertz gyrotron that have generated more than 200 kW at 295 GHz. This gyrotron is a prototype of a power source of collective Thomson scattering diagnostics in LHD. The other is a basic study of continuously frequency tunable gyrotron. A self-consistent numerical code that calculates oscillation frequency as a function of the magnetic field strength at the cavity has been developed. A demountable type test gyrotron to verify the design calculation with this code has been fabricated. A preliminary study proved the concept of continuous frequency tunability based on backward wave oscillation. A sealed-off gyrotron based on this concept will be produced in FY 2013.

Interaction of oscillation modes through the electron beam has been studied. Nonlinear hard self-excitation of a parasitic fundamental harmonic mode with an assist of a second harmonic mode has been observed. This is confirmation of a theoretical prediction. The two modes interact through bunching of the cyclotron rotation phase of the electron beam. This is a typical example of charged particles and EM fields.